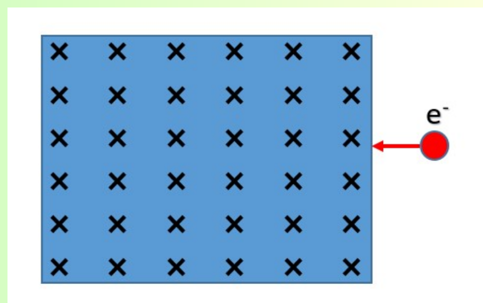
Magnetic fields	**Charged particles in a magnetic field**

Learning objectives	**MUST (C)**	Qualitatively explain the path of a charged particle in a uniform magnetic field
	SHOULD (B)	Calculate the force on a charged particle in the uniform magnetic field
	COULD (A/A*)	Analyse the motion of a charged particle in both an electric and magnetic field

STARTER: An electron enters a region in which there is a uniform magnetic field. How will it move? Think about the force that will act upon it. Sketch your idea.

EXTENSION: A proton enters the same magnetic field at the same velocity. Sketch and explain its path.



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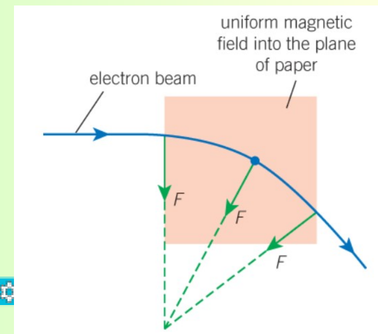
MUST (C)	Qualitatively explain the path of a charged particle in a uniform magnetic field

A moving charged particle in an electric field will experience a force, which can be predicted using Fleming's LH rule.

Task: Sketch the diagram.
a) Verify for yourself, using Fleming's LH rule, that the direction is correct.
b) What is the relationship between the movement and the force?
c) How, if at all, would the speed of the electron change?
Ext: If the field was larger and the electron had stayed in it, how would its movement have continued?



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The force, F, always acts perpendicular to the velocity of the electron.
The speed does not change, because the force has no component in the direction of motion.
Because the force is always perpendicular to the velocity, a charged particle will move in a circle.

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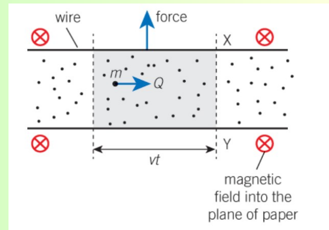
SHOULD (B)	Calculate the force on a charged particle in the uniform magnetic field

Deriving the equation for the force on a charged particle in a uniform magnetic field:



Particles, charge *Q*, moving at speed *v* at right angles to uniform magnetic field of flux density *B*.

In time *t*, all charged particles in shaded region pass through section XY.

We know that F = BIL

L = vt

Substitute in: F = BIvt

If there are N charged particles in the shaded region, how could we express the current, I?

I = NQ/t

Substitute into the earlier equation:

F = B x NQ/t x vt

t cancels: F = BNQv

This is the force on this section of our conductor. To find the force on an individual particle, divide by N (as there are N particles, each with a small share of the force).

F = NBQv/N, so F = BQv

Activity

As the force is always perpendicular to the velocity, a charged particle will always move in a circle. An object moving in a circle has centripetal acceleration: a = v^2/r (velocity2/radius of the circle).

Use this equation and the expression that we have just derived to find an equation to determine the radius of the circle.

$$a = \frac{v^2}{r}$$

Can you use this to find the force on the particle?

Now equate this with the expression for F we just derived

and rearrange for r

Complete questions 2 and 3 from summary questions 23.3.

Extension: The Large Hadron Collider has a radius of 2804 metres in its curved section, and has a magnetic field of 8.33 T. Protons in the LHC travel at 0.99999999 *c*. What is their mass when accelerated?

2	$F = BQv = 0.20 \times 1.6 \times 10^{-19} \times 6.0 \times 10^5$	[1]
	$F = 1.92 \times 10^{-14}\ \text{N} \approx 1.9 \times 10^{-14}\ \text{N}$	[1]
3	$BQv = \frac{mv^2}{r}$ therefore $mv = BQr$ ($p = mv$)	[1]
	$p = 0.130 \times (2 \times 1.6 \times 10^{-19}) \times 0.025$	[1]
	$p = 1.04 \times 10^{-21}\ \text{kg m s}^{-1}$	[1]

Extension: $m = \frac{rBQ}{v}$ $\quad m = \frac{2804 \times 8.33 \times 1.602 \times 10^{-19}}{0.99999999 \times 3 \times 10^{8}}$

m = 1.2473 x 10^{-23} kg - how does this compare to rest mass?

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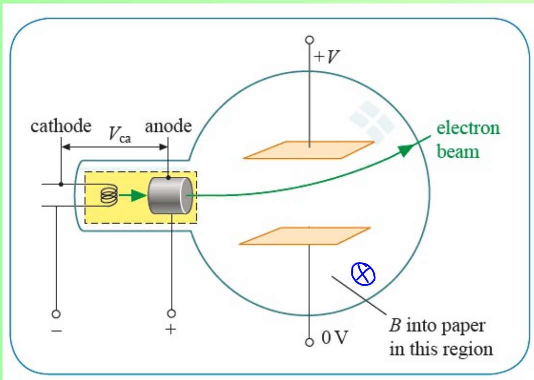
COULD (A/A*)	Analyse the motion of a charged particle in both a magnetic and electric field



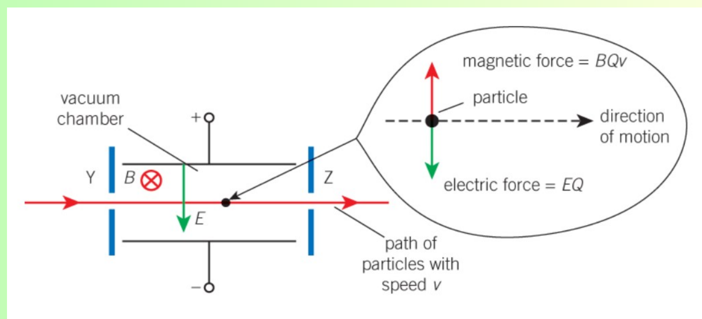
Cathode ray tube

For an **undeflected** particle in a magnetic field

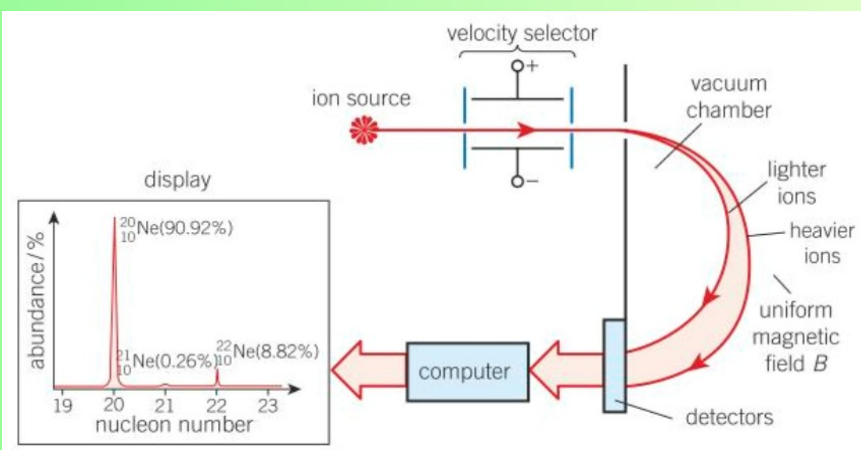
electric force = magnetic force

$eE = BQv$

$v = E/B$



Velocity selector - only allows particles of a certain velocity



A mass spectrometer uses a velocity selector so that all ions have the same velocity. Therefore, the radius only depends upon the mass and charge of the ion.

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An alpha particle moves at one-tenth the velocity of a beta particle. They both move through the same uniform magnetic field at right angles to their motion.

The magnitude of the ratio $\frac{\text{force on the alpha particle}}{\text{force on the beta particle}}$ is

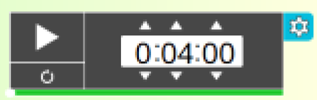
A $\frac{1}{4}$

B $\frac{1}{5}$

C $\frac{1}{10}$

D $\frac{1}{20}$

(Total 1 mark)



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